Fire scar and logging detection in the boreal forest using radar and optical sensors

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Abstract

Accurate analysis of disturbed areas in the boreal forest is important for understanding forest dynamics and the cycling of carbon. As part of the Siberian disturbance mapping project, this study evaluated the capability of three different radar sensors (ERS, JERS and Radarsat) and an optical sensor (Landsat 7) to detect fire scars and logging in the boreal forest.

Using Battacharraya Distance analysis, this study found that Landsat7 data was superior to combined radar data sets for discriminating among disturbance classes. The combined use of radar and Landsat did improve overall results.

Study Site

The Boguchany test site of the Siberian Disturbance Mapping project is located at 97^o 25’ E and 59^o 2’ N, 75 km North of the Angara River and 350 km East of the Yeniseisk River in Western Siberia.

The area is considered one of the most important sites for timber logging in Siberia [4]. Pine (Pinus spp.) and Larch species (Larix spp.) cover most of this landscape, however other conifers, such as Spruces (Picea) and fir (Abies, ssp.), can also be found in patches the area. Deciduous stands such as birch and aspen species (Betula ssp.) cover the areas of lower elevation in this region. The elevation of the study site ranges from 150-550 m.

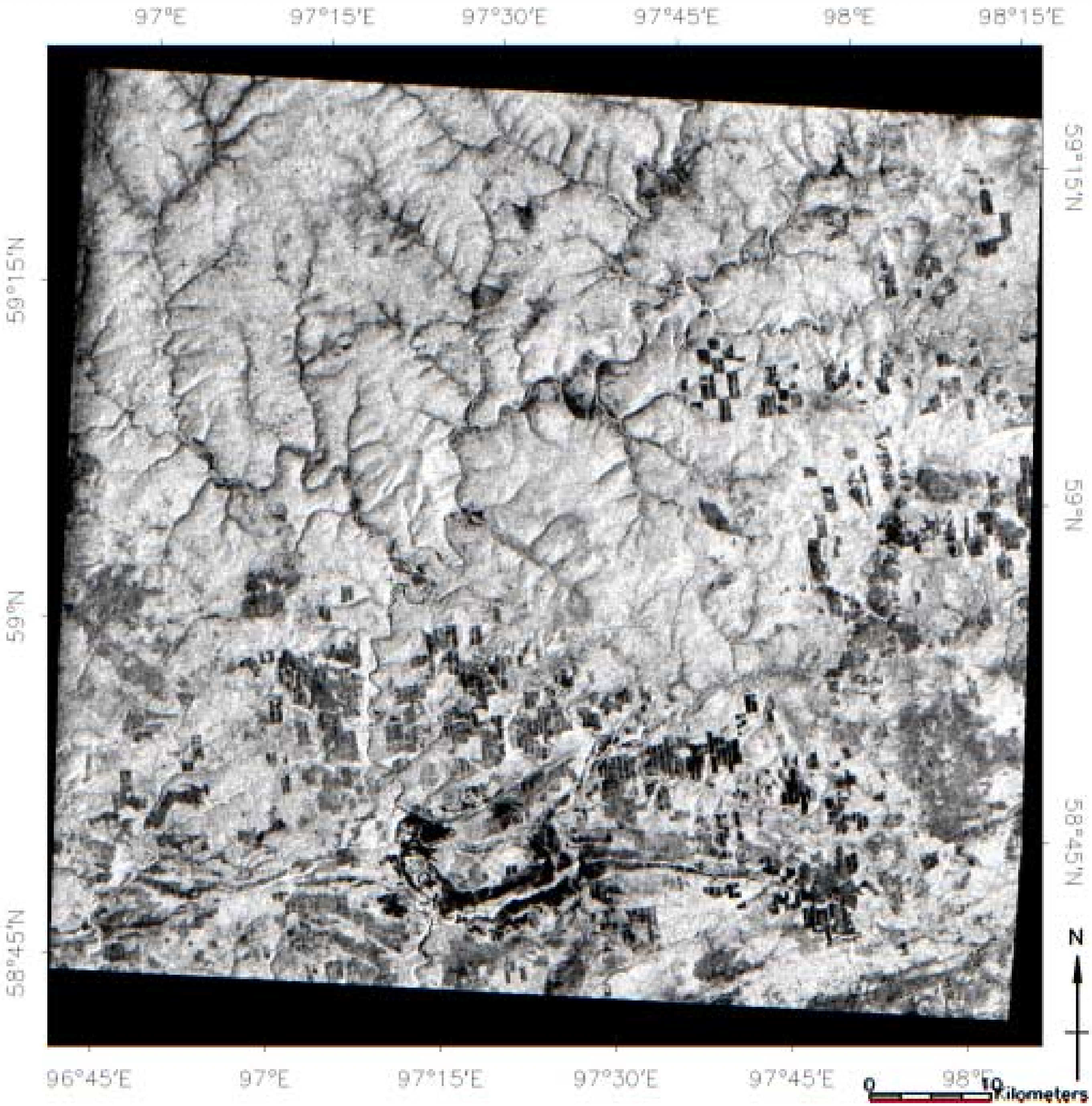
In the summer, smoke plumes from burning wild fires obscure the ground. Fire is the principal factor that determines ecosystem dynamics in this region and therefore most of the stands are of pyrogenic origin [7]. The fires that caused the fire scars in this study were ignited by lightening and extinguished by rainfall. This study will focus on the two largest fire scars in the area. Both fires burned in 1996. Scientist from the Sukachev Institute of Forest surveyed the site in the fall of 1999. The field surveys included GPS and plot measurements.

Location of the Boguchany area in Western Siberia

Image Data Information

Sensor	JERS	ERS-1	Radarsat ST4
Frequency (GHz)	L band (1.275)	C band (5.3)	C band (5.3)
Wavelength (cm)	23.5	5.66	5.66
Polarization	HH	VV	HH
Inc. angle (deg)	38.9	23	34
Image Center	58.01N, 97.43E	97.55N, 59.49E	97.33N, 59.10 E
Orbital Direction	Descending	Descending	Ascending
Image Swath (km)	75	100	100
Altitude (km)	580	785	798
Data take dates	3-Mar-97,27-Jun-98	7-Jun-98, 2-Aug-99	21-Aug-99
Pixel size (m)	12.5	12.5	12.5

	Landsat 5	Landsat 7	Landsat 7
Data Take Date	3-Sep-91	31-Jul-99	Oct. 3, 1999
Image Center	58.71N,96.81 E	58.71N, 96.81 E	58.71N, 96.81 E
Path and Row	P141 R19	P141 R19	P141 R19
Resolution (m)	30	30	30
Sensor	TM	ETM+	ETM+
Cloud cover (%)	0	10	0
Bands	7	7 + pan	7 + pan



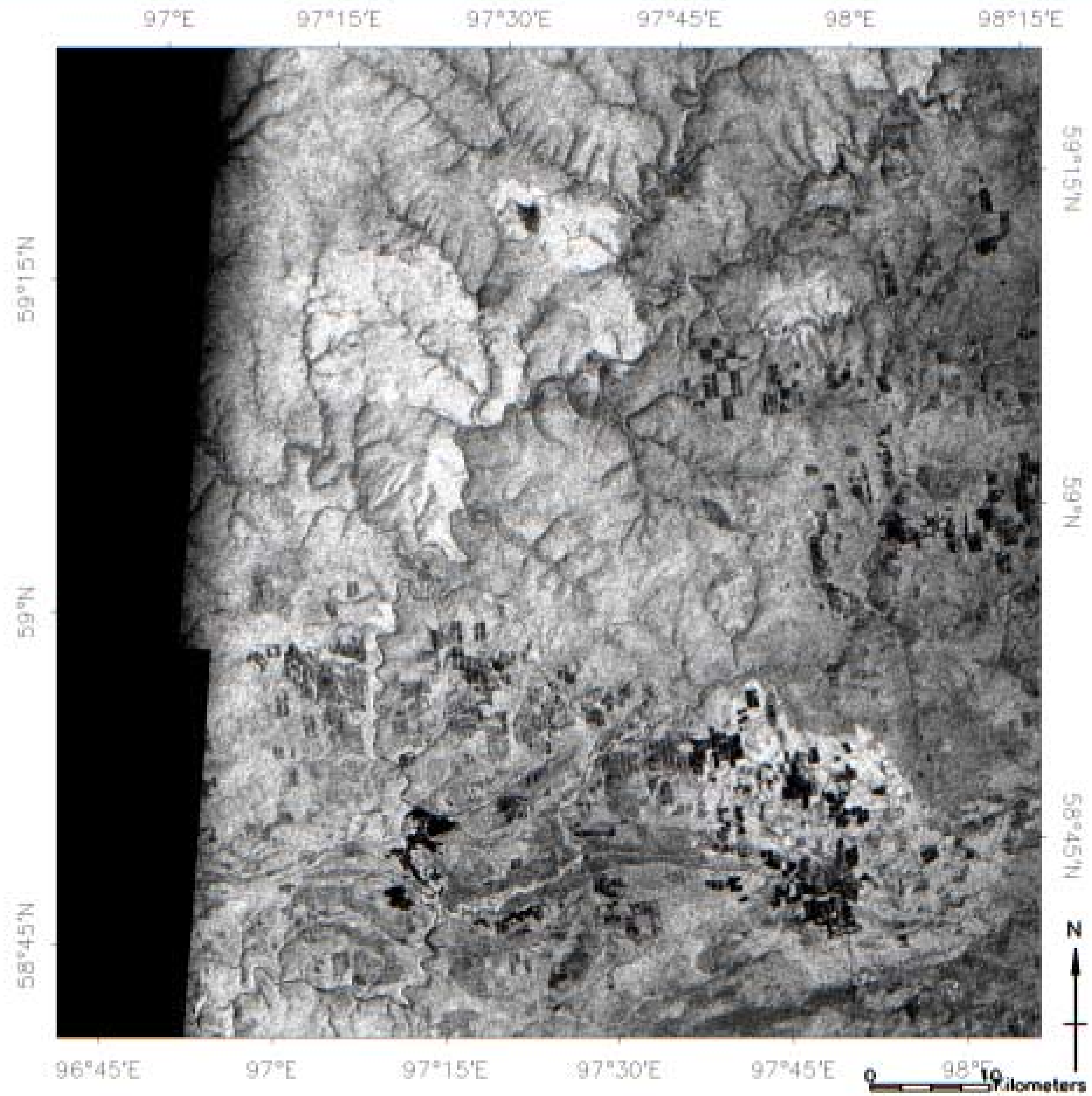
JERS

Date: 31-Mar-97

Band: L

Polarization: HH

Inc. angle: 38.9deg



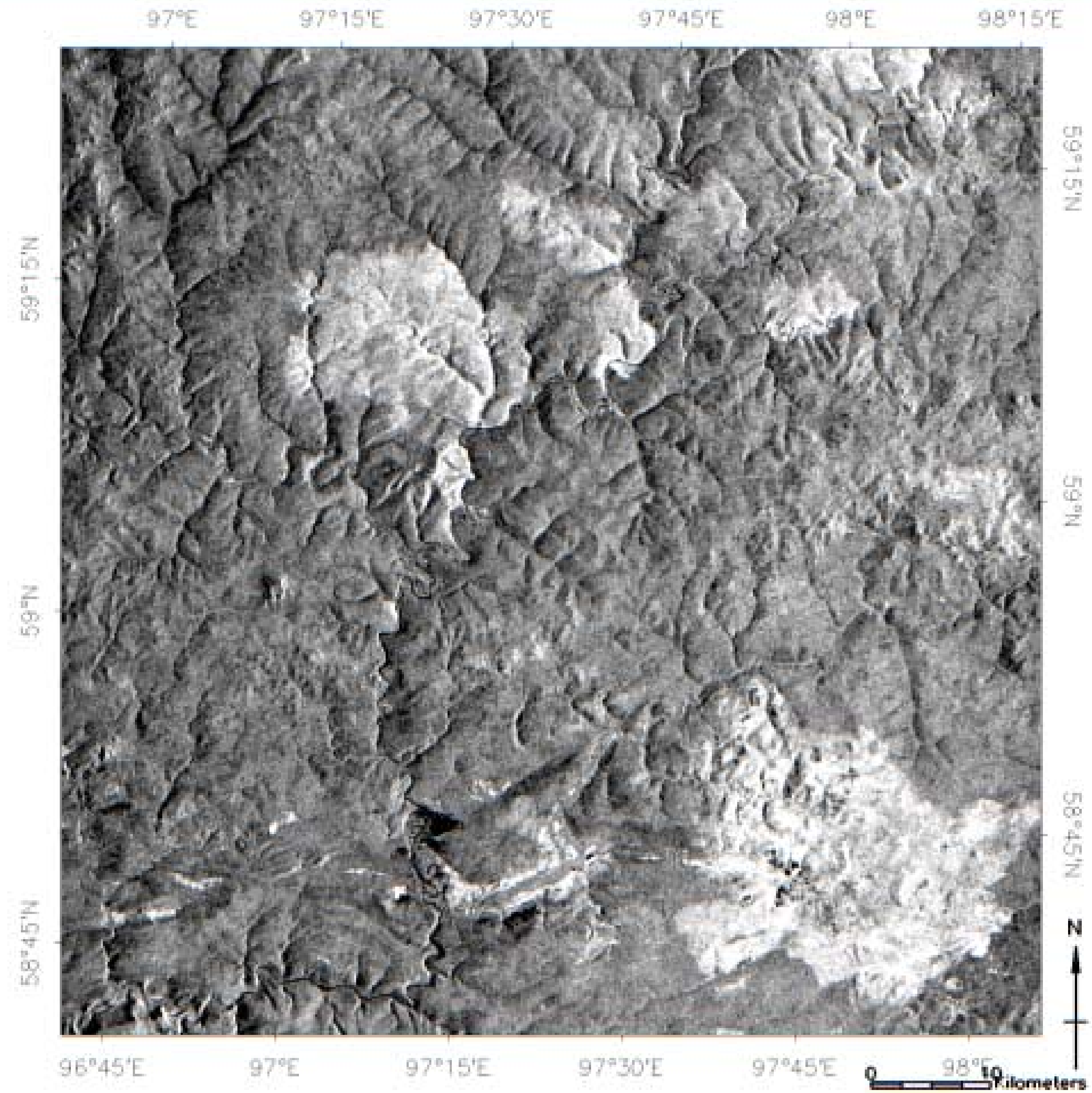
JERS

Date: 27-Jun-97

Band: L

Polariz.: HH

Inc. angle: 38.9 deg



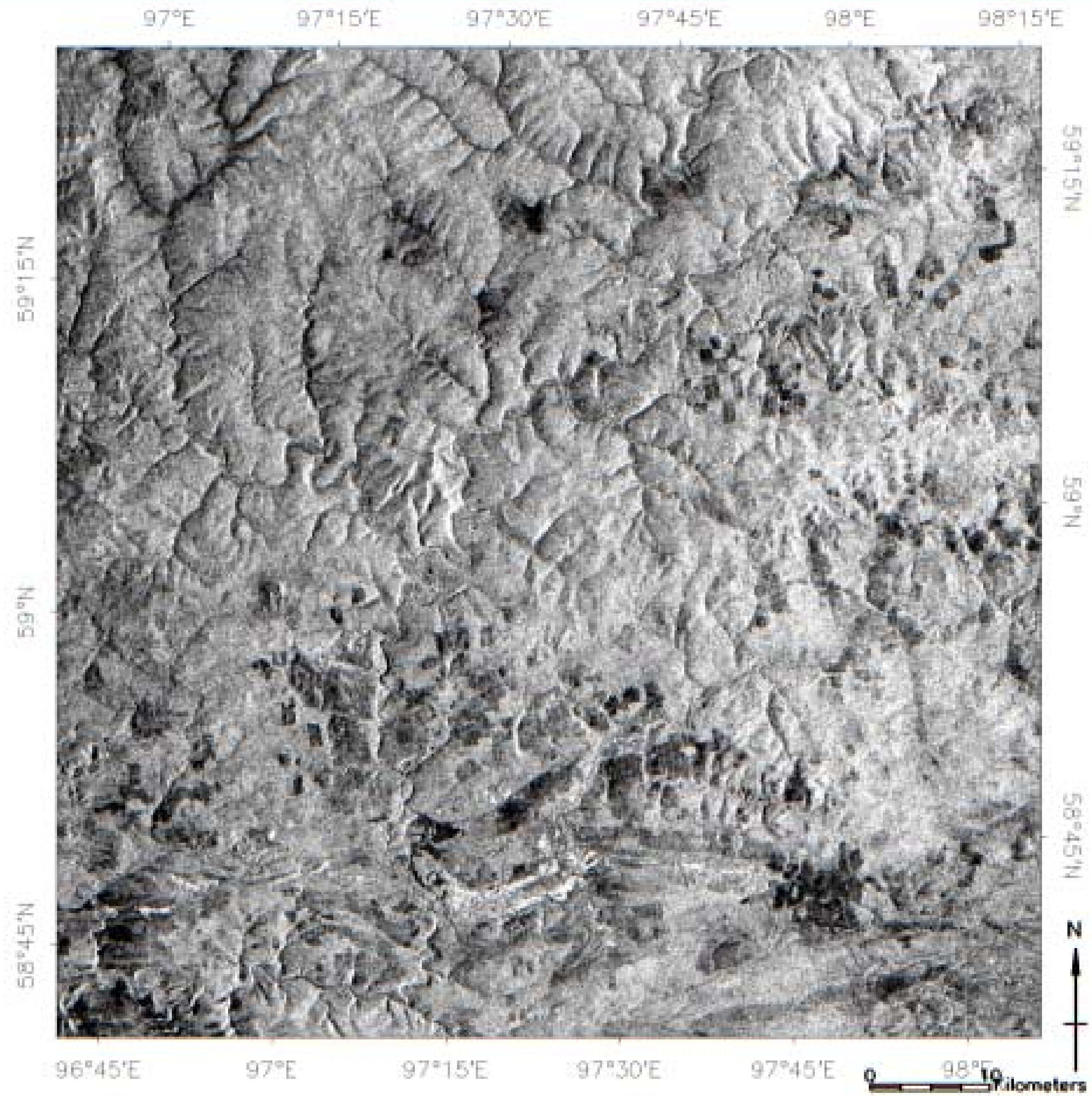
ERS-1

Date: 7-Jun-98

Band: C

Polarization: VV

Inc. angle: 23.3deg



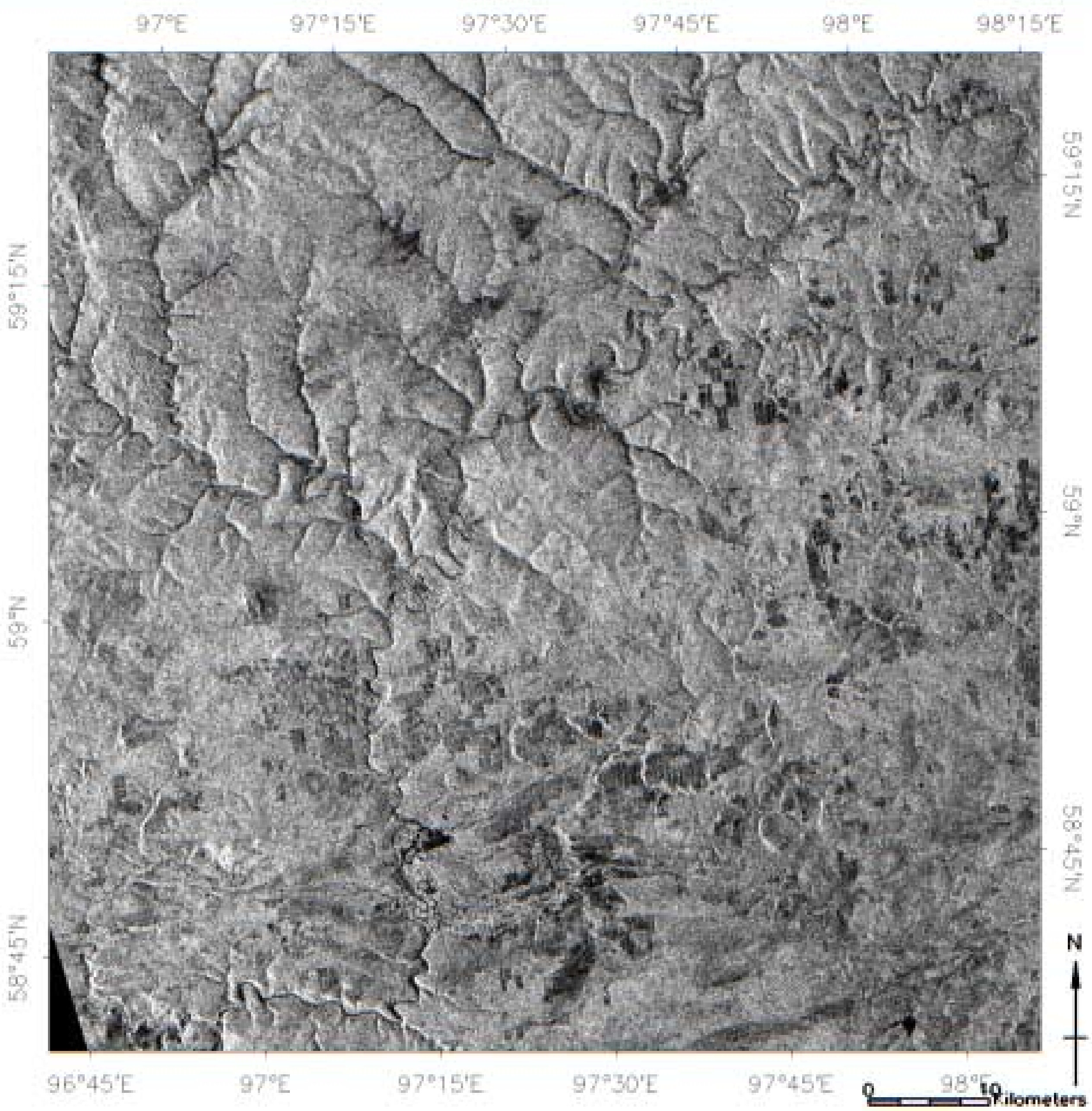
ERS-1

Date: 2-Aug-99

Band: C

Polariz.: VV

Inc. angle: 23.3 deg



Radarsat ST4

Date: 21-Aug-99

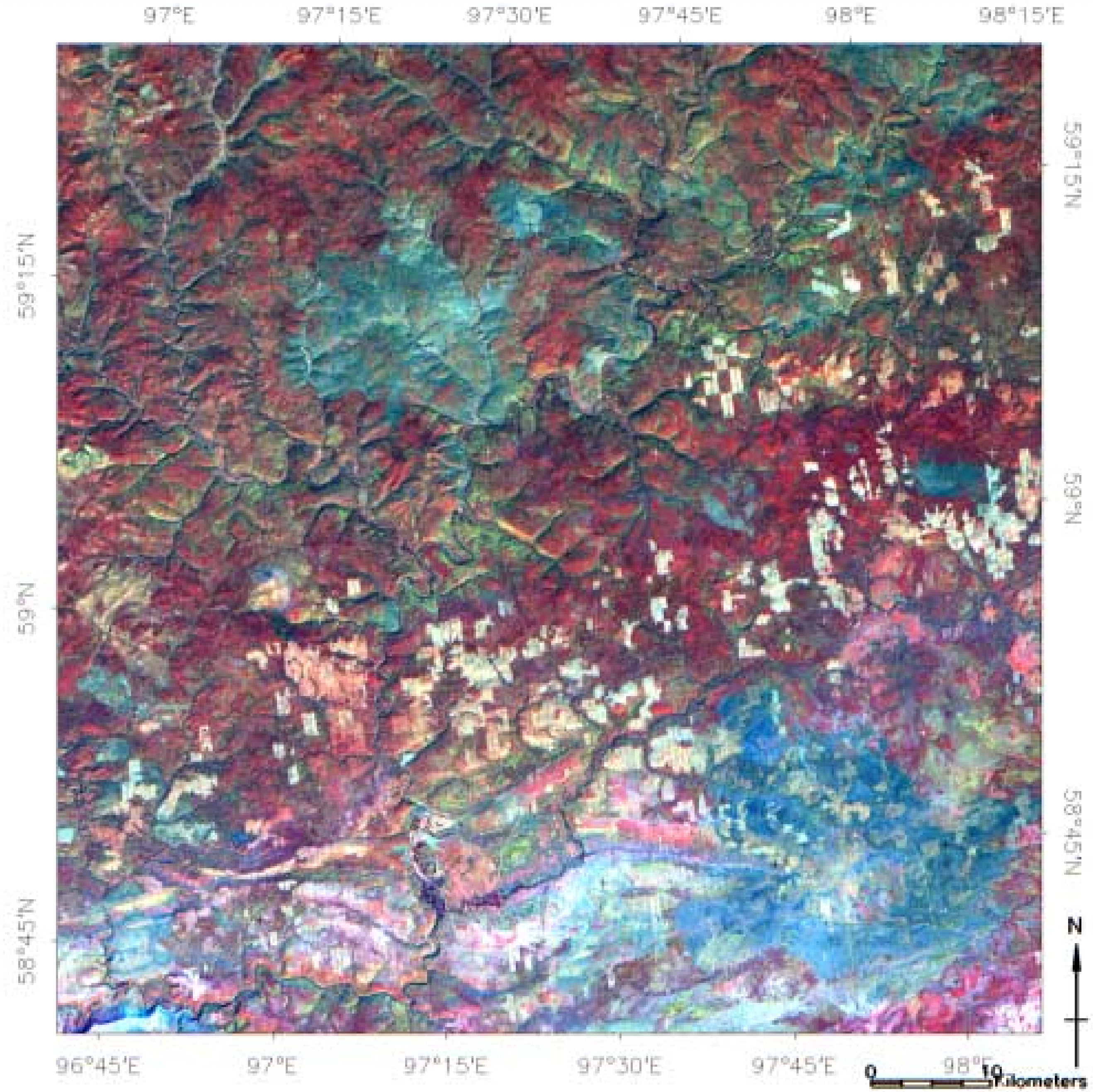
Band: C

Polarization: HH

Inc. angle: 34.0 deg

Microwave Data

JERS (LHH, March 31, 1997), ERS-1 (CVV, June 7, 1998), and Radarsat (CHH, Aug. 21, 1999) data were used to determine to what extent these different sensors could detect the presence of fire scars and clear cuts. The ERS, JERS and Radarsat data were resampled to 25 m pixel size, rotated (if necessary), wrapped onto a longitude/latitude grid using corner coordinates (if necessary), filtered using a 3 by 3 Frost filter and reprojected to the Lambert Conformal Conic with WGS 84 datum. There was no radiometric terrain correction applied to the radar images because the of the low topography across the 75 km by 75 km study area. Additional images were acquired for JERS and ERS to see if there was a seasonal effect.



Landsat7 RGB image

Date: 10/3/1999

Red: NIR (band 4)

Green: Red (band 3)

Blue: Blue (band 1)

Optical and Auxiliary Image Data

The cloud free Landsat 7 ETM+ scene, acquired on Oct. 3, 1999 was subsetted and reprojected to the Lambert Conformal Conic with WGS 84 datum. As auxiliary data, this project used Landsat 5 TM (Sept. 9, 1991) and Landsat 7 ETM+ (July 31, 1999) data. These optical data were used in conjunction with ground-based information such as maps, photos and local field knowledge to identify, ascertain and locate the different vegetation and burn classes and their training sites on the radar images.

To attain greater geometric accuracy and to ensure that the six data sets were co-registered with the highest possible accuracy, the JERS, ERS, Radarsat and Landsat 5 data were registered to the latest Landsat 7 because Landsat 7 has high geodetic accuracy.

Vegetation Classes

By incorporating disturbed classes relevant to this area (such as logging and fire scars) into the IGBP-DIS land cover classes, using field surveys, auxiliary information and image data, the following vegetation classes were determined: Coniferous forest (CF), Deciduous forest (DF), Post-cutting regeneration/Sparse Forest (RS), Clear cuts (CC), Burned coniferous forest (BC), Burned deciduous forest (BD), Burned clear cut and post-cutting regeneration (BL).

The training sites for these classes were determined based on the information gathered in the field, the multi-year and multi-season coverage provided by the three Landsat scenes and the contextual information provided by the individual Landsat scenes.

Results and Discussion

Initial analysis with single band radars showed very poor discrimination among all disturbed classes. The results of the BD analysis for the three radar bands combined are shown on Table 1. The average separability was 1.399 which indicates that even three radar sensors may not be suitable to discriminate all of these classes to a high enough accuracy. However, certain classes, such as post cutting regeneration/sparse forest and burned deciduous forest, clear cuts and burned deciduous forest, and ‘burned clear cuts and post-cutting regeneration’ and coniferous forest were discriminated with high accuracy.

Separability Analysis

The purpose of the Bhattacharyya Distance (BD) [5] analysis was to determine how well each sensor was separating each land cover class. The BD was calculated for (1) the three radar sensors (ERS, JERS and Radarsat) combined (3 bands), for (2) the reflective Landsat 7 bands combined (6 bands), and (3) for the radar and optical sensors combined (9 bands). BD values over 1.9 represent adequate separability between classes for classification. Initial analysis with single band radars showed very poor discrimination among all disturbed classes. The results of the BD analysis for the three radar bands combined are shown on Table 1.

TABLE 1						
ERS, JERS AND RADARSAT SEPARABILITES						
class	CF	DF	RS	CC	BC	BD
DF	0.12819					
RS	1.74129	1.69377				
CC	1.82178	1.79706	0.49316			
BC	1.26280	1.33321	1.84184	1.76733		
BD	1.33342	1.41488	1.93320	1.88794	0.40797	
BL	1.88934	1.87803	0.97153	0.33964	1.59521	1.84749
AVG	1.39900					
MIN	0.12819	CF&DC				
MAX	1.93320	RS&BD				

TABLE 2						
LANDSAT7 SEPARABILITIES						
class	CF	DF	RS	CC	BC	BD
DF	1.77133					
RS	1.96002	1.76623				
CC	1.99852	1.98395	1.77380			
BC	1.99676	1.98642	1.99414	1.99551		
BD	1.99981	1.97253	1.97471	1.95954	1.63150	
BL	1.99968	1.90824	1.72523	1.05302	1.91204	1.33698
AVG	1.84286					
MIN	1.05302	CC&BL				
MAX	1.99981	CF&BD				

TABLE 3						
ERS, JERS, RADASAT AND LANDSAT7 SEPARABILITES						
class	CF	DF	RS	CC	BC	BD
DF	1.82049					
RS	1.99306	1.95523				
CC	1.99986	1.99751	1.82718			
BC	1.99864	1.99217	1.99889	1.99953		
BD	1.99990	1.98852	1.99764	1.99723	1.73889	
BL	1.99996	1.98771	1.86145	1.24376	1.97767	1.93101
AVG	1.91935					
MIN	1.24376	CC&BL				
MAX	1.99996	CF&BL				

Battacharrayya Distance Values

The average separability was 1.399 which indicates that even three radar sensors suitable to discriminate all of these classes to a high enough accuracy. However, certain classes, such as post cutting regeneration/sparse forest and burned deciduous forest, clear cuts and burned deciduous forest, and ‘burned clear cuts and post-cutting regeneration’ and coniferous forest were discriminated with high accuracy. Classes with very low separabilities included coniferous and deciduous forest, and burned coniferous and burned deciduous forests. This indicates that high separability values occurred where the vegetation classes had different structural characteristics, such as in the case of clear cuts (no large trunks standing) and deciduous forest (presence of dead trunks).

The results of classifying the area with the radar data only are in Table 2. The effect of the low BD values are seen as overall poor discrimination between classes. It does appear that though the radars do not discriminate types of forest or disturbance they may be able separate forest from disturbance.

Table 3 shows the BD values for the reflective Landsat 7 bands. Here the average separability was 1.843. Highest separabilities (consistently above 1.9) were found for the deciduous forest class and the disturbed classes, and the coniferous forest class and the disturbed classes. The classification confusion table for the Landsat data is presented in Table 4.

TABLE4								
CONFUSION MATRIX FOR RADAR CLASSIFICATION								
Areas	rcent Pixel Classified by Code							
Code	Pixels	CF	DF	RS	CC	BC	BD	BL
CF	8483	65.50	25.20	0.90	0.00	1.40	6.90	0.00
DF	6318	45.90	45.30	2.70	0.20	0.30	5.40	0.10
RS	8320	2.40	1.60	77.40	12.70	0.50	0.30	5.00
CC	6921	0.70	1.60	22.00	49.00	0.30	0.40	26.00
BC	6145	6.40	2.20	0.30	0.20	51.70	36.40	2.80
BD	5580	3.10	3.80	0.00	0.10	13.50	79.30	0.20
BL	9462	0.20	0.30	8.40	16.80	3.40	0.30	70.60
Average accuracy=	62.70%				Confide	Level :		
Overall accuracy=	63.51%				99%	0.57191	+/- 0.00639	
Kappa Coefficient=		0.57191			95%	0.57191	+/- 0.00486	
Standard Deviation =		0.0028			90%	0.57191	+/- 0.00408	

TABLE5								
CONFUSION MATRIX FOR LANDSAT7 CLASSIFICATION								
Areas	rcent Pixel Classified by Code							
Code	Pixels	CF	DF	RS	CC	BC	BD	BL
CF	8483	98.00	1.80	0.10	0.00	0.00	0.00	0.00
DF	6318	1.20	94.10	2.70	0.40	0.10	0.10	1.40
RS	8320	0.20	2.70	93.80	1.90	0.00	0.00	1.30
CC	6921	0.10	0.40	2.50	88.40	0.00	0.00	8.50
BC	6145	0.10	0.70	0.10	0.00	95.40	3.00	0.70
BD	5580	0.00	0.60	0.30	0.00	3.20	91.10	4.80
BL	9462	0.00	0.60	2.30	17.00	0.60	8.00	71.50
Average accuracy=	90.35%				Confide	Level :		
Overall accuracy=	89.60%				99%	0.87829	+/- 0.00407	
Kappa Coefficient=		0.87829			95%	0.87829	+/- 0.00309	
Standard Deviation =		0.00158			90%	0.87829	+/- 0.00260	

TABLE 6								
CONFUSION MATRIX FOR RADAR AND LANDSAT 7 CLASSIFICATION								
Areas	rcent Pixel Classified by Code							
Code	Pixels	CF	DF	RS	CC	BC	BD	BL
CF	8483	98.40	1.50	0.00	0.00	0.00	0.00	0.00
DF	6318	1.20	97.20	0.60	0.60	0.10	0.10	0.30
RS	8320	0.10	1.50	95.90	1.70	0.00	0.00	0.80
CC	6921	0.10	0.30	2.20	89.80	0.00	0.00	7.50
BC	6145	0.10	0.50	0.00	0.00	95.70	3.00	0.60
BD	5580	0.00	0.60	0.30	0.00	2.50	95.30	1.30
BL	9462	0.00	0.00	1.40	10.40	0.80	0.60	86.70
Average accuracy=	94.15%				Confide	Level :		
Overall accuracy=	93.87%				99%	0.92818	+/- 0.00321	
Kappa Coefficient=		0.92818			95%	0.92818	+/- 0.00244	
Standard Deviation =		0.00124			90%	0.92818	+/- 0.00204	

Confusion Matrices

Table 5 shows the separability values for the radar sensors and the six Landsat 7 bands combined. Here, the average separability improved to 1.919 and an overall increase in the separability of all classes was observed. The classification results (Table 6) show a slight increase in accuracy for most classes except for areas burned after logging (BL) which increased by 15%. The average accuracy was 94.2% and the kappa coefficient was 0.93. The classification accuracy was above 90% for all classes with the exception of the clear-cut (CC) class that was confused with the ‘burned clear cut and post cutting regeneration’(BL) class and vice versa. In Fig. 1. the classification based on the combined three radar bands and six Landsat 7 bands is shown.

Classification Surface View

Based on

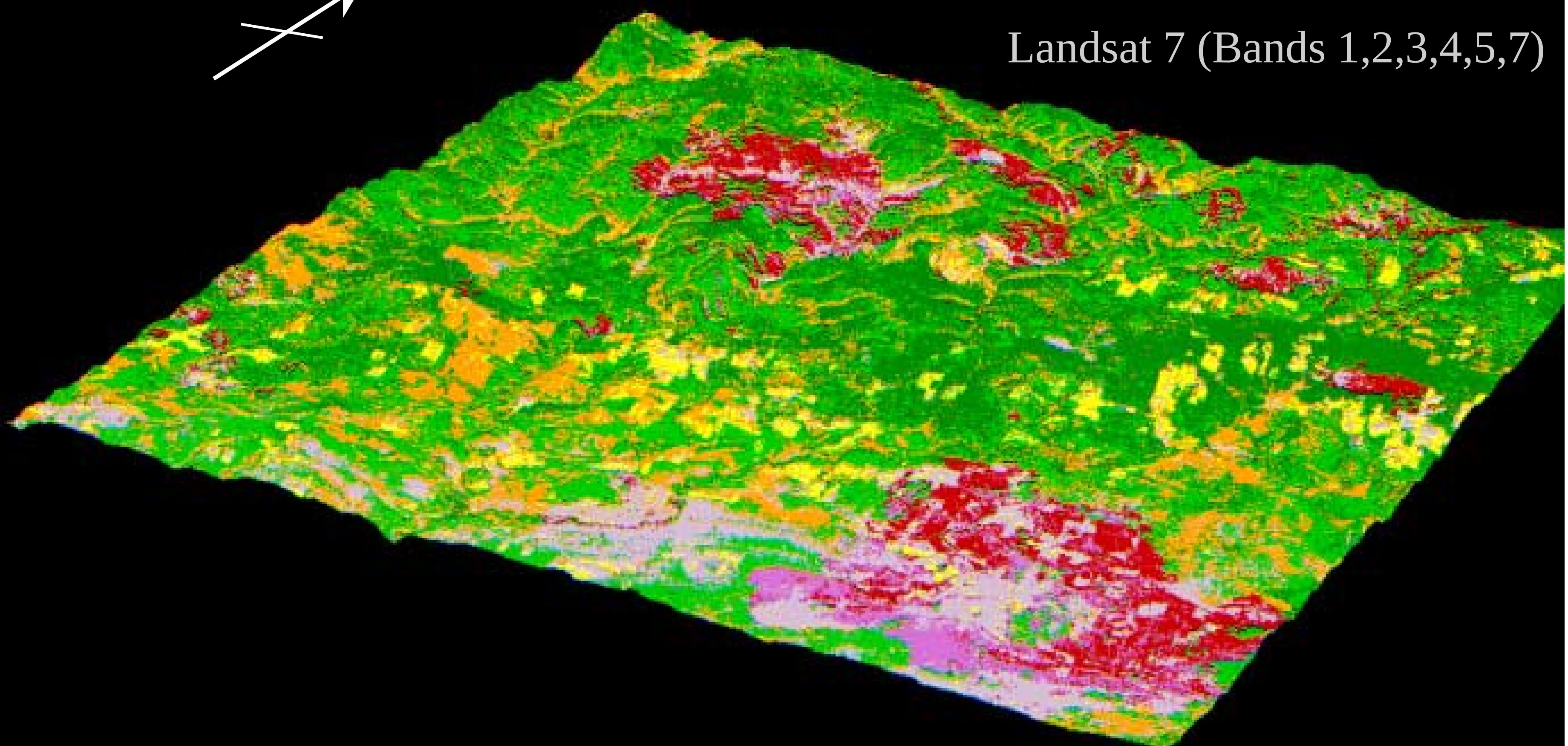
JERS (LHH),

ERS-1 (CVV),

Radarsat (CHH) and

Landsat 7 (Bands 1,2,3,4,5,7)

N



Vertical exaggeration:

Conclusions

This work shows that radar analyses, even when combining three different sources, may not be sufficient for mapping fire and logging disturbances in our area. The study does demonstrate that Landsat 7 data was superior to the radars, but results do improve when the optical and microwave are combined. It is suggested that this improvement results from the radar's sensitivity to structural differences (important for logged areas) with the optical sensor's sensitivity to spectral differences (important for burned areas) among the classes.

Because of the high frequency of cloud cover and long periods of low or no solar illumination routine monitoring by optical sensors such as Landsat may not be feasible. This work suggests that radars with their "all weather" capability may be used to detect evidence of disturbance routinely. However, before this is possible the effects of environmental conditions such as surface mositure on disturbance detection must be better understood.

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